

## LCA Methodology

# A Weighting Method for the Korean Eco-Indicator

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### Abstract

A weighting factor proposed in this paper is a product of a reduction factor ( $N_i/T_i$ ) and a relative significance factor ( $f_i$ ). A politically determined critical impact ( $T_i/f_i$ ) is assumed to cause a critical damage defined as a level of damage acceptable to a society. A graph showing the relationship between relative damage and normalized impact indicates that the weighting factor ( $(N_i/T_i) f_i$ ) is the slope of this graph. It shows further that the relative damage is the same as the weighted impact.

**Keywords:** Critical impact; damage; reduction factor; relative damage; relative significance factor; weighting

## 1 Background

In 1998, the Korean government launched a project that develops Korean Eco-Indicators for typical materials, processes and waste disposal methods. This project is similar to the Eco-Indicator 95 project in the Netherlands [1]. The Korean Eco-Indicator development requires a weighting method that allows aggregating impact from various impact categories into a single score.

Weighting is defined as an optional element of the Life Cycle Impact Assessment (LCIA) phase in which the data from the Life Cycle Inventory (LCI) analysis or the indicator results are ranked and possibly aggregated, and may include the use of subjective judgement and value choices [2]. In general, environmental impacts of a product system in LCA may be classified into three different types: characterized, normalized and weighted impact [3]. The first two types of the impact are associated per impact category and the last per product system.

A characterized impact ( $CI$ ) is an impact calculated by multiplying  $Load_i$  by its equivalency factor,  $eqv_{i,j}$ , for a given impact category  $i$ , i.e.

$$CI_{ij} = Load_i \times eqv_{i,j}$$

$$CI_i = \sum_j Load_j \times eqv_{i,j} \quad (1)$$

A normalized impact ( $NI$ ) is an impact calculated by dividing the characterized impact ( $CI_i$ ) by a normalization reference ( $N_i$ ) for a given impact category  $i$ . [A normalization reference is the total characterized impact calculated on the basis of an inventory of all the society's activities over a reference period of time [3]. Thus,

$$NI_i = \frac{CI_i}{N_i} \quad (2)$$

A weighted impact ( $WI$ ) is an impact calculated by multiplying the normalized impact by a weighting factor,  $W_i$ . That is:

$$WI_i = NI_i \times W_i \quad (3)$$

Fundamental question resides in the selection of  $W_i$ . There are three general approaches in selecting  $W_i$  values. They are the panel method, the monetization method and the distance-to-target method [4]. From these, the distance-to-target method has been used rather widely.

Typical examples would include the Eco-Indicator 95 [1], the Dutch and Swedish Environmental Theme method [5] and the Danish EDIP method [3]. The weighting method for the Korean Eco-Indicator is based on the concept of the Dutch Eco-Indicator 95 and the Danish EDIP method; thus, the weighting schemes used in those methods are the starting point for the development of a weighting method for the Korean Eco-Indicator. Each of these two methods adopted a weighting scheme based on the distance-to-target method.

## 2 Analysis of the Distance-to-Target Method

The distance to target method defines  $W_i$  as:

$$W_i = \frac{N_i}{T_i} \quad (4)$$

where

$T_i$  = Target reference of an impact category  $i$ : An impact where no discernable impact is observed in a given environment.

Frequently  $N_i/T_i$  is termed as a reduction factor. Substituting  $N_i$  in equation (2) and  $W_i$  in equation (4) into equation (3) gives:

$$WI_i = \frac{CI_i}{N_i} \frac{N_i}{T_i} = \frac{CI_i}{T_i} \quad (5)$$

From equation (5), it is evident that the distance-to-target method is in fact not a weighting method. Dividing  $CI_i$  by  $T_i$  results in an expression which is another form of normalization [4]. The denominator has changed from a normalization reference ( $N_i$ ) to a target reference ( $T_i$ ). Thus, weighted impact in equation (5) is not a weighted impact but a normalized impact. The reason for using  $N_i/T_i$  is because of difficulties in estimating  $T_i$ ; while a reduction factor is relatively easy to obtain. Most of the time,  $N_i/T_i$  is a politically determined reduction factor.

In addition to the problem described above, there is a fundamental problem in using  $N_i/T_i$  as a weighting factor in calculating the weighted impact. By using  $N_i/T_i$  as a weighting factor, we implicitly assume that each impact category is equally important. This is because  $N_i/T_i$  only indicates the degree of seriousness of a given impact category. It does not indicate anything in terms of relative significance among different impact categories.

Let's take an example. A reduction factor for eutrophication, which is a local impact, indicates the distance between current impact ( $N_i$ ) and target impact ( $T_i$ ). The distance between these two values reflects the seriousness of that specific impact category, in this case eutrophication, in a given environmental condition, here, local environment. Thus, a reduction factor does not provide any indication as to the relative significance among different impact categories. This suggests that the distance-to-target method alone should not be used as a weighting method.

There are several specific problems in using  $N_i/T_i$  as a weighting factor. One of the specific problems is that receiving environment affected by a given impact category is different from one impact category to another. For global impacts, the receiving environment is the global environment. For regional and local impacts, the receiving environments are regional and local environments, respectively. Furthermore, global impacts are considered more serious than regional and/or local impacts.

Other specific problems include the degree or rate of reversibility and scientific uncertainty of a given impact category. In general, reversible impacts are considered less serious than irreversible impacts. A reversible impact with a shorter recovery time is considered less serious than that with a longer recovery time. Those impacts with scientifically known consequences are considered less serious than those with scientifically uncertain consequences [6].

The above-mentioned viewpoints are called the precautionary principle. This principle has frequently been applied to

determine the relative significance of impact categories in the panel method. Giving a weighing factor to each impact category is the same as comparing the relative significance among different impact categories. From these discussions, it is evident that the distance-to-target method is not a weighing method. This is because the method only deals with the degree of seriousness within a given impact category.

### 3 Method Development

Weighing between safeguard areas requires the selection of the types of safeguard area. This selection may be made based on the goal of today's human society. "Our Common Future" [7] may indicate that realization of a sustainable society would be the goal. If this were the case, the resource and ecosystem would be a good choice for the safeguard areas. These safeguard areas suffer damages resulting from activities such as resource consumption and environmental emissions of a product system.

It is quite subjective to judge whether resource or ecosystem is more important to the realization of a sustainable society. Giving equal weight to these two safeguard areas may be acceptable, although it may never be agreed, in light of the fact that both are essential components for a sustainable society. However, it is controversial as to the selection of safeguard areas. For example, whether human health is a separate safeguard area or belongs to the ecosystem still needs to be resolved. Because of reasons cited above, no attempt was made to develop a weighting scheme between safeguard areas. Rather, an emphasis was given to resolving the weighting issue between impact categories within a given safeguard area.

A panel method such as the Delphi-like method has been used widely in giving a weighting factor to an impact category; however, it lacks a specific consideration of each impact category. In other words, the Delphi-like process did not consider the degree of seriousness of a given impact category as in the case of the distance-to-target method. Thus, a new approach is needed to give a weighting factor to each impact category.

The new approach proposed in this paper is to combine a reduction factor in the distance-to-target method and a relative significance factor based on the precautionary principle in giving a weighting factor to each impact category. The relative significance factor may be determined based on methods such as the Analytical Hierarchy Process [8] or Multiple Hierarchy Process [8]. These methods are subjective in nature because value judgement is involved; however, it is inevitable to exercise value judgement because the relative significance between impact categories in itself requires value judgement.

Thus, a proposed weighting factor is expressed in equation (6):

$$W_i = \frac{N_i}{T_i} f_i \quad (6)$$

where

$f_i$  = relative significance factor for the  $i$ th impact category: it indicates the relative significance of an impact category with respect to other impact categories within a given safeguard area.

The logic for equation (6) is that a weighting factor should take into account the degree of seriousness of the impact in a given impact category (a reduction factor) as well as the degree of relative significance of the impact among different impact categories (a relative significance factor). The former indicates an internal aspect of an impact category and the latter external aspect, or external relationship among different impact categories. This approach is an advancement of using either the distance-to-target method or the panel method alone in the weighting factor determination.

A basic premise of the proposed weighting factor in equation (6) is that  $N_i/T_i$  and  $f_i$  are independent. The value of  $N_i/T_i$  can be determined solely based on the degree of seriousness of the  $i$ th impact category. The determination of the value of  $f_i$ , however, may be affected by the value of  $N_i/T_i$  if the Delphi-like method is used, although each expert in a panel is requested only to consider the relative significance between impact categories solely based on the precautionary principle. This is because the judgement of an expert is reflected directly to the value of  $f_i$  in cases making use of the Delphi-like method. Therefore, methods like AHP or MHP should be employed in determining the value of  $f_i$  instead of the Delphi-like method. The Korean National Training Institute of Statistics published the values of relative significance factor for various environmental categories, which is similar to  $f_i$  in concept, using the AHP method [9].

A weighting factor in equation (6) is identical in its formula to that of Goedkoop [1]. However, the meaning of the formula is completely different. Table 1 lists the difference between the weighting method by Goedkoop and that presented in this paper.

Table 1 indicates that the weighting factor developed in this paper is different from that of Goedkoop [1].

Table 1: Difference between two weighting methods

Parameter	GOEDKOOP	This paper
$W_i$	<ul style="list-style-type: none"> <li>subjective weighting factor</li> <li>expresses the <u>seriousness of an impact</u></li> </ul>	<ul style="list-style-type: none"> <li>relative significance factor (<math>f_i</math>)</li> <li>expresses the <u>relative significance between impact categories</u></li> </ul>
$N_i/T_i$	weighting factor	not a weighting factor
Weighting factor	$N_i/T_i$	$f_i \cdot N_i/T_i$

Substituting  $W_i$  in equation (6) and  $N_i$  in equation (2) into equation (3) gives:

$$WI_i = \frac{CI_i}{N_i} \frac{N_i}{T_i} \cdot f_i \quad (7)$$

Since  $f_i$  takes into account the relative significance among different impact categories, equation (7) can be summed up for all  $i$  to obtain weighted impact of a product system:  $WI$ . Thus,

$$WI = \sum_i WI_i = \sum_i \frac{CI_i}{N_i} \frac{N_i}{T_i} \cdot f_i \quad (8)$$

A damage is the end result of an impact. There are many types of impact. However, there is only one damage. Here, the recipient of damage is the sustainable society. Thus, damage in this context should be interpreted as a damage to the realization of a sustainable society. A critical damage ( $D_c$ ) is defined in this paper as a level of damage acceptable to a society. A critical damage is therefore a level of damage acceptable to the realization of a sustainable society.

An impact causing the critical damage is called a critical impact. A critical impact may be determined politically or ecologically. The former is called a politically determined critical impact and the latter an ecologically determined critical impact. In general a politically determined critical impact is easier to estimate than an ecologically determined critical impact. A politically determined critical impact is determined by a combination of a politically determined target reference,  $T_p$ , for a critical impact and the relative significance of that impact category,  $f_i$ . Here, a politically determined target reference,  $T_p$ , is assumed to be a result of a compromise among scientific facts, economics and social ethics, all aimed at the realization of a sustainable society.

Under the premise of using politically determined critical impact in this weighting method,  $T_p/f_i$  is a politically determined critical impact. Figure 1 is a modification of a graph

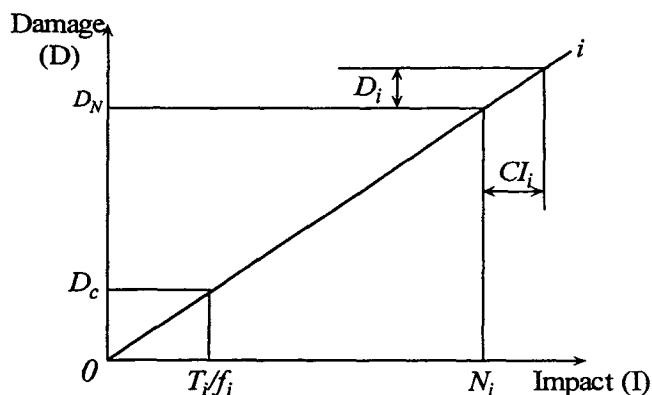


Fig. 1: Relationship between damage and impact  
 $D_i$  = damage due to characterized impact  $CI_i$   
 $D_N$  = damage corresponding to  $N_i$

illustrating the relationship between damage and impact from the Eco-Indicator 95 method [1]. As was assumed in the Eco-Indicator 95 method, the relationship between damage and impact was assumed linear in this paper. Figure 1 shows the relationship between  $T_i/f_i$  and critical damage. (Note: The bigger the  $T_i$  and the smaller the  $f_i$  the impact category in question gives less damage to the environment. This means that a less serious impact for a given critical damage would require a bigger value of  $T_i/f_i$ )

A relative damage defined as a damage related to a critical damage is useful in deriving a relationship between critical damage and politically determined critical impact. Figure 2 shows the relationship between relative damage and normalized impact.

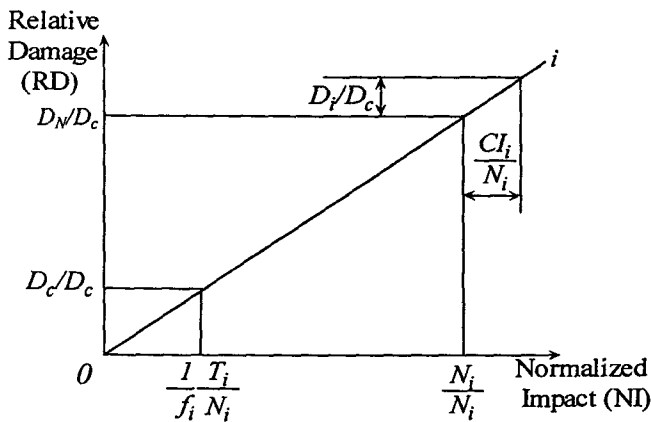


Fig. 2: Relationship between relative damage and normalized impact of a product system with a single impact category  
 $D_N/D_c$  = damage corresponding to  $N_i/N_i$

The analysis of the graph in Fig. 2 results in the following relationships.

$$\text{slope}_i = \frac{D_i/D_c - 0}{\frac{1}{f_i} \frac{T_i}{N_i} - 0} = \frac{N_i}{T_i} f_i \quad (9)$$

Also,

$$\text{slope}_i = \frac{D_i/D_c}{CI_i/N_i} \quad (10)$$

Rearranging equation (10) with respect to relative damage gives:

$$\frac{D_i}{D_c} = \frac{CI_i}{N_i} \times \text{slope}_i \quad (11)$$

Substituting  $\text{slope}_i$  in equation (9) into equation (11) gives:

$$\frac{D_i}{D_c} = \frac{CI_i}{N_i} \frac{N_i}{T_i} f_i \quad (12)$$

The right hand side of equation (12) is exactly the same as that of equation (7). This means that the weighted impact is the same as the relative damage, i.e.

$$WI_i = \frac{D_i}{D_c} \quad (13)$$

Also, from equations (6) and (9), a weighting factor of a given impact category is the slope of the impact category graph in Fig. 2, i.e. the slope of a graph depicting the relationship between relative damage and normalized impact for a given impact category, i.e.

$$W_i = \text{slope}_i = \frac{N_i}{T_i} f_i \quad (14)$$

Most product systems, however, consist of multiple impact categories. A graph similar to Fig. 2 shows the relationship between relative damage and normalized impact for a product system with multiple impact categories ( $\rightarrow$  Figure 3).

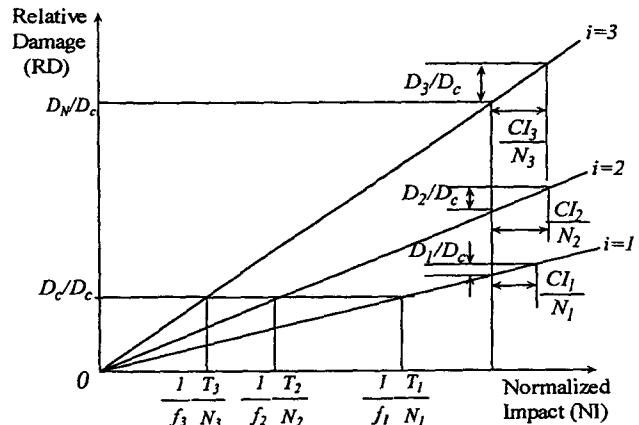


Fig. 3: Relationship between relative damage and normalized impact of a product system with multiple impact categories

Based on the premise given above that there is only one damage, although there are many different types of impact, different types of critical impact result in the same critical damage as shown in Fig. 3. However, the magnitude of the critical impact that results in the same critical damage is different among different impact categories. This is because each impact category is different in nature and thus requires a different amount of impact to cause damage to the realization of a sustainable society.

Clearly the estimation of the critical damage would be quite difficult. It is not the intention of this paper to present a method for the estimation of a critical damage. Rather, this paper attempts to develop a weighting method based on a concept that different types of impacts cause a single type of damage, i.e. damage to the realization of a sustainable society.

The purpose of Fig. 3 is to show relative damage caused by different impact categories in a given product system. Relative damage caused by each impact category in a given product system,  $D_i/D_c$ , is shown as a function of normalized impact of the product system,  $CI_i/N_i$  in Fig. 3. Since the slope of the graph in Fig. 3 or the  $i$ th weighting factor incorporates the relative significance among different impact categories, the relative damage shown in Figure 3 can be additive. Therefore, the total relative damage caused by a product system is:

Total relative damage caused by a product system

$$= \sum_i D_i / D_c = \sum_i \frac{C_i}{N_i} \frac{N_i}{T_i} f_i \quad (15)$$

From equation (15) and (8), the total relative damage caused by a product system is the same as the total weighted impact caused by a product system. In other words, weighted impact is synonymous to relative damage.

The purpose of introducing the concept of critical damage and relative damage in Figs. 1 to 3 is to support the logic for the selection of weighting factors and the weighting procedure in the weighting method proposed in this paper. Of particular interest is to show the relationship between normalized impact and relative damage. After all, the damage caused by an impact is of concern. A graphical presentation helps us to visualize damage caused by an impact. Since it is impractical to predict absolute damage, a relative damage is of use in quantifying the impact caused by a product system.

#### 4 Conclusion

A weighting factor proposed for the Korean Eco-Indicator is a product of a reduction factor ( $N_i/T_i$ ) in the distance-to-target method and a relative significance factor ( $f_i$ ) based on the precautionary principle. Politically determined critical impact ( $T/f_i$ ) is assumed to cause a critical damage that is defined as a level of damage acceptable to the realization of a sustainable society. A graphical relationship between rela-

tive damage and normalized impact indicates that weighting factor ( $(N_i/T_i) f_i$ ) is the slope of this graph. An eco-indicator of a product system is the total weighted impact or total relative damage of that product system.

#### Acknowledgement

Financial support for this research was provided by the Ministry of Commerce, Industry and Energy through the industrial foundation fund of the Republic of Korea. The author wishes to thank Mr. Sug SANGWON for his assistance in preparing and typing this paper.

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Received: September 15th, 1998  
Accepted: February 16th, 1999

## LCA Certification in Italy

# LCA Certification According to ISO 14.040: First Experience

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#### Introduction

This paper presents a project which is a first experience of LCA certification according to ISO Standard 14.040.

After its publication in June 1997, the ISO Standard 14.040 received a great deal of attention from many companies interested in an LCA application to their processes: the possibility of obtaining a certificate to demonstrate the accuracy of this application, in fact, is now more attractive than in the past.

Since ISO 14.040 has a very flexible structure, it is possible to adapt the standard to the process under investigation and to address any suggested improvements using a well planned and standardised framework.

The procedure described here can certainly be improved in order to reach particular goals, but it clearly constitutes a starting point to make LCA studies more reliable and transparent. Indeed, it is an accurate application of LCA framework require-

ments with the new possibility of a non-interested party guarantee. In particular, the certification authority guarantees the effort of the company towards a continuous improvement of environmental performances of the analysed product system. In fact, while it was sufficient to entrust the study to a well known LCA practitioner in the past, it is now more convenient to certify the completeness and reliability of the study by a fourth party, i.e. the external reviewer.

#### The investigated process

The LCA study was held at ABB Kent Taylor S.p.A. and was performed by ABB Corporate Research Italy, in co-operation with process engineers. The certification procedure, described later in this paper, took about four months, while the entire analysis lasted approximately one year.